Optical design for high-fidelity imaging spectrometry

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ABSTRACT

In this talk, the techniques for achieving high response uniformity from a pushbroom imaging spectrometer are discussed, and spectrometer system examples are given that maximize SNR and uniformity.

1. INTRODUCTION

Imaging spectrometry is an important technique for the remote monitoring of ecosystems. Accurate extraction of spectroscopic and spatial information from a remotely sensed scene places strict demands on the performance of an imaging spectrometer system.[1] High signal-to-noise ratio (SNR), accurate and stable calibration, and spectral and spatial uniformity of response are necessary.[2] All that must be accomplished within a tight volume and mass budget, especially for spaceborne systems. Concentric imaging spectrometers[3,4] offer unique advantages in terms of compactness and uniformity of response. Variations of those forms can cover practically all applications with a spectral resolution requirement down to ~1nm in the visible to mid-infrared range.

2. NEW SPECTROMETER MODULES FOR AVIRIS

NASA's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS)[5,6] is perhaps the most successful spectrometer system, having operated continuously for more than 12 years and having collected terabytes of information. Its whiskbroom architecture allows it to suppress most spectral artifacts. The use of four spectrometers to cover the 400-2500 nm range permits high grating efficiency, and the large pixel size (200 μm) and aperture (f/1.1) contribute to high SNR. For these reasons, AVIRIS has been used as a calibration standard for other imaging spectrometers using simultaneous data acquisition over a given area.

A concentric design allows substantial size reduction of the AVIRIS spectrometer modules, while at the same time offering the potential of increased calibration stability. Figure 1 compares the present AVIRIS spectrometer design, in which three aspheric surfaces are used, with a concentric design of the Dyson form (bottom) that has the same specifications and somewhat better design performance.
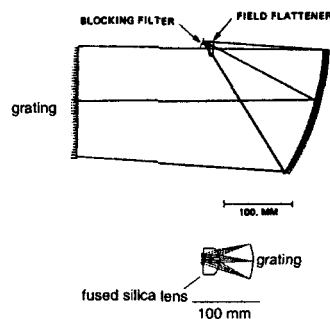

Figure 1: Present (top) and new AVIRIS spectrometers

The Dyson design uses only two spherical and one flat surface. Similar modules have been designed for all four AVIRIS spectrometers.

Implementation of these new modules hinges on availability of blazed gratings on the steeply curved substrate. Holographic techniques followed by directional ion etching offer one possibility, but have difficulty handling the shallow blaze angles required. There is an ongoing effort to generate the needed gratings through electron-beam and X-ray lithography techniques.

3. A MINIATURE SPECTROMETER FOR OCEAN COLOR MAPPING

The full potential of the Dyson form is better demonstrated in a pushbroom design, which is advantageous for spaceborne systems due to increased SNR over the whiskbroom form. The low reflectivity of seawater makes it necessary to use a fast system. The spectrometer example shown below has been optimized for the detection of phytoplankton photosynthetic pigment signatures. The spectral range is 340-800 nm. High SNR is achieved through a relatively large pixel (25 μm) and large relative aperture (f/1.7). The spectral

sampling is 2.9 nm, and there are 512 spatial pixels. CCD arrays of the highest quality are available with those characteristics. Figure 2 shows the system schematic.
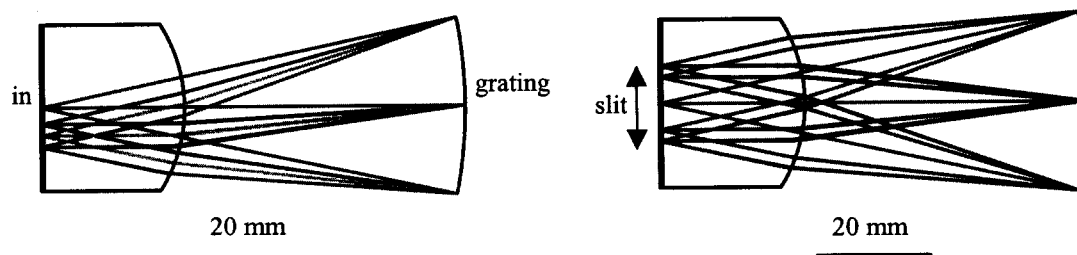

Figure 2: A miniature Dyson imaging spectrometer. Left: y-z view shows spectrum. Right: x-z view shows slit length. The slit and its image are almost coincident in that view. The input beam is normally reflected out of the image plane by the use of a small mirror (not shown).

This spectrometer system has no spectral or spatial distortion and a total spectral nonuniformity[7] of less than 1% at the design level. The spatial nonuniformity of this design will be typically limited by the front telescope, which is a demanding design in its own right.

4. A FULL-RANGE SYSTEM FOR LAND COVER/ ECOSYSTEM MONITORING

For a spectrometer system covering the full 400-2500 nm range, it is advantageous to use the reflective Offner form. The system shown in Fig. 3 has two spectrometer modules, each covering the complete spectral range with two focal planes and a dichroic beamsplitter, reflecting the short wavelengths.
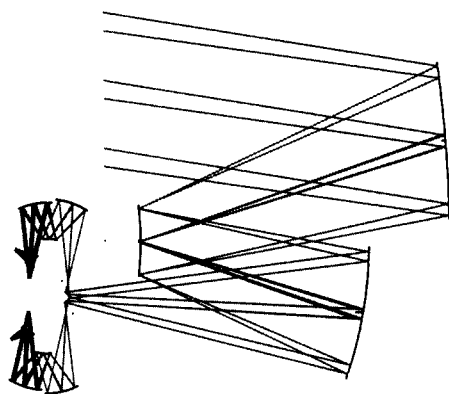

Figure 3: A wide field, full spectrum hyperspectral imager. The two spectrometer modules on the left are on different planes (above and below the paper plane).

The F-no is 2.8, which is about the minimum that can be achieved with this type of design and all spherical optics. Each spectrometer has 640 spatial pixels of 27 μm size, giving a total FOV of 1280 pixels. The spectral sampling is ~9 nm for λ > 1000 nm, and 4.5 nm for λ < 1000 nm. The grating operates in first and second order simultaneously, and has two different blaze areas to achieve the broadband response. The total system spectral nonuniformity is less than a few percent. The front telescope was designed to provide a 40 km swath from an altitude of 705 km. Achieving a spatial uniformity value of less than a few precent, which is more critical for land observations also hinges on the image quality of the telescope, which is close to diffraction-limited by design.

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